1,165,190

PATENT SPECIFICATION

DRAWINGS ATTACHED

1,165,190

Date of Application (No. 57053/66) and filing Complete Specification: 20 Dec., 1966.

Application made in United States of America (No. 515,393) on 21 Dec., 1965.

Complete Specification Published: 24 Sept., 1969.

Index at acceptance:—E1 F44

International Classification:—E 21 b 43/14

COMPLETE SPECIFICATION

Well Completion Apparatus

We, TEXACO DEVELOPMENT CORPORATION, a Corporation organized under the laws of the State of Delaware, United States of America, of 135 East 42nd Street, New York 17, State of New York, United States of America, do hereby declare the invention, for which we pray that a Patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to well completion, and in its more specific aspects, to apparatus for controlled production of hydrocarbons from a plurality of hydrocarbon-bearing productive formations simultaneously through a pair of tubing strings.

In well completion as envisioned by this invention, a single wellbore is drilled through a plurality of vertically spaced hydrocarbon-bearing productive formations which are separated by relatively impermeable, non-productive formation. When desired, casing may be cemented in the borehole by conventional methods. A pair of tubing strings are arranged in the borehole extending from the surface and passing through a plurality of hydrocarbon-bearing productive formations. When casing is used, vertically spaced apart packing members are arranged in the casing annulus to isolate each hydrocarbon-bearing productive formation from the others. A mandrel, having an open tubing bore adapted for fluid communication with the bore of one of the tubing strings, upon connection thereinto, is located in the proximity of an isolated hydrocarbon-bearing productive formation, and is provided with a suitable inlet for establishing communication therewith. Hydrocarbon fluids from the productive formation are allowed to pass into and through the mandrel and through the tubing strings to the surface. In one embodiment, the mandrel is provided with an inlet chamber with inlet communication with an isolated hydrocarbon-bearing productive formation. A flow regulating device positioned at the outlet of the inlet chamber controls the flow of fluids from the productive formation through the mandrel. A by-pass is provided around that section of the the open tubing bore adjacent the inlet chamber for by-passing production fluids from other formations.

A flowmeter, which is adapted to be lowered in the said one of the tubing strings is retrievably arranged in the mandrel. This flowmeter is provided with an inlet and gas and liquid outlets, and first and second spaced apart packers are located above and below the inlet, thereby providing a fluid-tight seal to prevent passage of fluids from other hydrocarbon-bearing productive formations through the flowmeter, while directing fluids from the adjacent isolated productive formation through the flowmeter.

When the mandrel is interposed in the said one of the tubing strings adjacent a productive formation and a flowmeter is arranged in the mandrel as explained above, fluids from the productive formation enter the mandrel through the flow regulating device and pass through the flowmeter on the way to the surface. Means is provided for receiving and recording the signals transmitted from the flowmeter to the surface. It is important that fluids from other productive formations are separately directed through the bypass and past the flowmeter such that these fluids do not enter the flowmeter. Where it is desired to meter another hydrocarbon-bearing productive formation, the flowmeter is raised or lowered in the tubing string by such means as a wire line, and the flowmeter is positioned in another mandrel located adjacent an isolated hydrocarbon-bearing productive formation. Fluids from that formation, upon being lifted to the surface through the tubing strings, are metered through the flowmeter.

In Patent Specification No. 1,105,949 there is disclosed an apparatus for flowing wells initially and for later artificial lift by means of the gas lift method for use in wells with casing

so that the casing-tubing annulus provides a channel for the power gas for the gas lift operation, which would require a higher formation pressure. The present invention differs thereover by being applicable specifically for use with a beam pumping system and to permit full depletion of low pressure reservoir by operating with only atmospheric pressure on the producing formation. Hence the ultimate recovery will be greater. Further, the apparatus is applicable particularly to open hole, tubingless completions, although it is possible to use the apparatus in that part of the wellbore which may have casing installed.

According to the present invention, there is provided well completion apparatus for use in multiple zone completion using a pair of tubing strings in a well-bore penetrating a plurality of vertically spaced, hydrocarbon-bearing productive formations separated by relatively impermeable, non-productive formations, said apparatus comprising for each productive formation a mandrel interconnected into one of said pair of tubing strings, said mandrel comprising a tubing bore which is substantially coaxial with the bore of said one tubing string, an inlet chamber offset from said tubing bore, and a bypass conduit connected at both ends to said tubing bore and adapted to bypass production fluids in said one tubing string past said inlet chamber, sealing means disposed between said tubing strings and said wellbore for isolating said formations from each other, an adjustable choke controlling the individual flow of production fluids through said inlet chamber, a flowmeter having spaced sealing means for sealing said tubing bore on both sides of said inlet chamber when said flowmeter is positioned in said tubing bore, said flowmeter providing inlet communication with respect to said choke and outlet communication with respect to said one of said tubing strings, and means for lifting production fluids to the surface above said formations via the other of said pair of tubing strings.

In order that the invention may be understood, it will now be described by way of example with reference to the accompanying drawings in which:—

Figure 1 shows an arrangement of the apparatus of the present invention in a borehole; and

Figure 2 is a sectional view showing in greater detail the mandrel used with the invention.

Referring to the figures of the drawing, numeral 10 designates a wellbore drilled from the earth's surface, wherein casing 12 has been cemented in place with cement 14. As shown in Figure 1, the well bore penetrates a plurality of vertically spaced apart hydrocarbon-bearing productive formations as designated by the letters A, B and C, which are separated by non-productive formations designated by the latters D, E, F and G. Tubing strings 18 and 20 are positioned in borehole 10 and extend vertically from the well head (not shown). In that part of the borehole having the casing, vertically spaced apart packing members 22 supported by the tubing strings are arranged in the casing to isolate a hydrocarbon-bearing productive formation, suitably for perforation. In the open hole part of the borehole, the ends of the tubing strings are joined together by tubing with a U configuration at 19, and are cemented in place by cement 14*a*. In some circumstances it may be feasible to have the tubing strings end in a sump at the bottom of the borehole (not shown).

For each productive formation, a mandrel, indicated generally at 24, is interconnected into tubing string (or inlet tubing) 18 in the proximity of the formation. Mandrel 24 is provided with a full open tubing bore 25 which is substantially coaxial with the bore of tubing string 18 and is adapted for fluid communication therewith. The connecting ends of mandrels 24 and tubing strings 18 are joined by couplings 26. An outwardly extending deformation or inlet chamber 28 in the wall of mandrel 24 is positioned so that the inlet chamber extends for a length less than the entire length of the mandrel, and has its longitudinal axis eccentrically disposed with relation to the longitudinal axis of the tubing bore 25 of the mandrel. It should be understood that the cross-section of the inlet chamber may be substantially elliptical or circular. Inlets to the chamber 28 are provided at the time of perforation of the productive formation as will be described later. A wire line retrievable choke 32, which desirably is adjustable, is positioned at the outlet 30 of the inlet chamber 28 for regulating the flow of fluids from the adjacent productive formation and for allowing communication between the isolated productive formation and the mandrel 24.

A retrievable sub-surface flowmeter 36 having inlet ports at 38 and gas outlet ports at 40 and liquid outlet ports at 42 is positioned in the bore 25 of mandrel 24 in the proximity of inlet chamber 28. First and second vertically spaced apart packets 46 and 48 are mounted on the flowmeter 36 and positioned within the bore 25 of the mandrel to isolate the inlet ports from the outlet ports. Mandrel 24 is provided with a bypass conduit 49, which is open to bore 25 at opposite sides of packs 46 and 48 for separably directing fluids from other productive formations past the flowmeter.

In operation, after the production mandrels 24 have been interconnected properly into tubing string or inlet tubing 18 so as to be adjacent the hydrocarbon bearing productive formations, and these formations isolated either by appropriate packers or by cement, the productive formations are perforated as indicated at 16, Fig. 2 by a perforator lowered into position into bore 25 of mandrel 24. Perforations are made through the wall of the in-

let tubing and the outer wall of the inlet chamber facing the productive formation and extending thereinto. The holes in the inlet tubing are sealed by insertion of an expansible sleeve 25*a*, and the perforations 16 have inlet communication with the inlet chamber 28 at the holes 28*a* in the outer wall of the inlet chamber. After positioning of the expansible sleeve 25*a* preventing direct communication between the productive formation and the bore 25 of the mandrel 24, the sub-surface flowmeter 36 is lowered into the tubing string 18 and positioned in the mandrel 24 adjacent the inlet chamber 28. The packers 46 and 48 mounted on the flowmeter are set to form a fluid-tight seal within the bore 25 thereby preventing passage of fluids from other hydrocarbon productive formations through the flowmeter. Fluids from each productive formation adjacent each mandrel are admitted to the mandrel via the holes 28*a* into the inlet chamber 28 to choke 32 at the outlet of the inlet chamber. The fluids enter the flowmeter through the inlet ports 38 and pass upwardly, if gas, through outlets 40 and downwardly, if liquid, through outlets 42 out of the flowmeter and commingle with production fluids previously metered through other mandrels adjacent other productive formations. The arrows in Figure 2 indicate the directions of flow. Upon passage of the fluids through the flowmeter, appropriate signals from the flowmeter are transmitted to the surface for recording, e.g. rate of flow, gas to oil ratio, basic sediment and water, volume, gravity and temperature.

The gas produced and metered from each productive formation is commingled in the inlet tubing 18 above each mandrel with that gas produced from lower productive formations and is collected at the surface by known means (no shown), while the liquids produced and metered from each productive formation are commingled in the inlet tubing 18 below each mandrel with those liquids produced from upper productive formations and collected at the U-shaped connection 19 between inlet tubing 18 and the tubing string or pump tubing 20, or alternatively in a sump (not shown) into which the inlet and pump tubings extend. The collected production fluids are then lifted to the surface by pumping through the pump tubing by pump 50 operated by known means e.g. a pumping beam with pump rods 51, shown partially in Fig. 1. Although gas lifting of the collected production fluids is possible in the manner disclosed in the above cited patent specification, the disclosed pumping system provides for full depletion of low pressure reservoirs as noted previously, which is not possible with the pressurized gas lift method.

It will be observed that the disclosed apparatus for use in well completion provides a number of advantages. The well-bore, both cased and open, passes through a plurality of hydrocarbon-bearing productive formations, and consequently any number of these productive formations can be produced simultaneously. This facilitates drilling operations, and eliminates additional equipment and materials thereby rendering the operation more economical. Flow of fluids from each productive formation can be regulated or controlled individually, or completely shut-in, by adjusting or changing the choke positioned in each mandrel. Fluids from each formation can be metered individually and separately by means of the sub-surface flow-meter. In addition, the tubingless completions in open boreholes result in lower costs, the inlet tubing providing for the collection of production fluids with the ability to test individual productive formations and the pump tubing providing the pumping of the production fluids. The completion is tubingless since no tubing is employed. Referring to Figure 1, the tubing 18 and 20 are part of the present device and are designated as the inlet tubing 18 and the pump tubing 20. If a tubing were to be installed in the wellbore 10, it would surround both tubings 18 and 20 in the manner similar to the way casing 12 now surrounds these tubings and mandrel at the top of Figure 1.

WHAT WE CLAIM IS:—

1. Well completion apparatus for use in multiple zone completion using a pair of tubing strings in a wellbore penetrating a plurality of vertically spaced, hydrocarbon-bearing productive formations separated by relatively impermeable, non-productive formations, said apparatus comprising for each productive formation a mandrel interconnected into one of said pair of tubing strings, said mandrel comprising a tubing bore which is substantially coaxial with the bore of said one tubing string, an inlet chamber offset from said tubing bore, and a bypass conduit connected at both its ends to said tubing bore and adapted to bypass production fluids in said one tubing string past said inlet chamber, sealing means disposed between said tubing strings and said wellbore for isolating said formations from each other, an adjustable choke controlling the individual flow of production on fluids through said inlet chamber, a flowmeter having spaced sealing means for sealing said tubing bore on both sides of said inlet chamber when said flowmeter is positioned in said tubing bore, said flowmeter providing inlet communication with respect to said choke and outlet communication with respect to said one of said tubing strings, and means for lifting production fluids to the surface above said formations via the other of said pair of tubing strings.

2. Apparatus according to claim 1, wherein said lifting means comprises a pump housed in said other of said pair of tubing strings.

3. Apparatus according to claim 1 or 2, wherein said sealing means comprises cement positioned in said wellbore in which said pair of tubing strings are embedded, said pair of

tubing strings are interconnected at their downhole terminals, said inlet chamber has open communication with said hydrocarbon-bearing production formation through perforations extending through said cement, and said flowmeter has separate gas and liquid outlets.

4. Apparatus according to claim 1 or 2, wherein said sealing means comprises packing members vertically spaced apart in said wellbore providing a sealed off section in the annulus between said wellbore and said tubing strings to isolate at least one of said hydrocarbon-bearing production formations from the other formations.

5. Well completion apparatus for use in a multiple zone completion using a pair of tubing strings in a wellbore substantially as described and shown in the accompanying drawings.

STEVENS, LANGNER, PARRY & ROLLINSON,
Agents for the Applicants.

Printed for Her Majesty's Stationery Office by the Courier Press, Leamington Spa, 1969.
Published by the Patent Office, 25 Southampton Buildings, London, W.C.2, from which copies may be obtained.

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1 SHEET This drawing is a reproduction of the Original on a reduced scale

Fig.1.

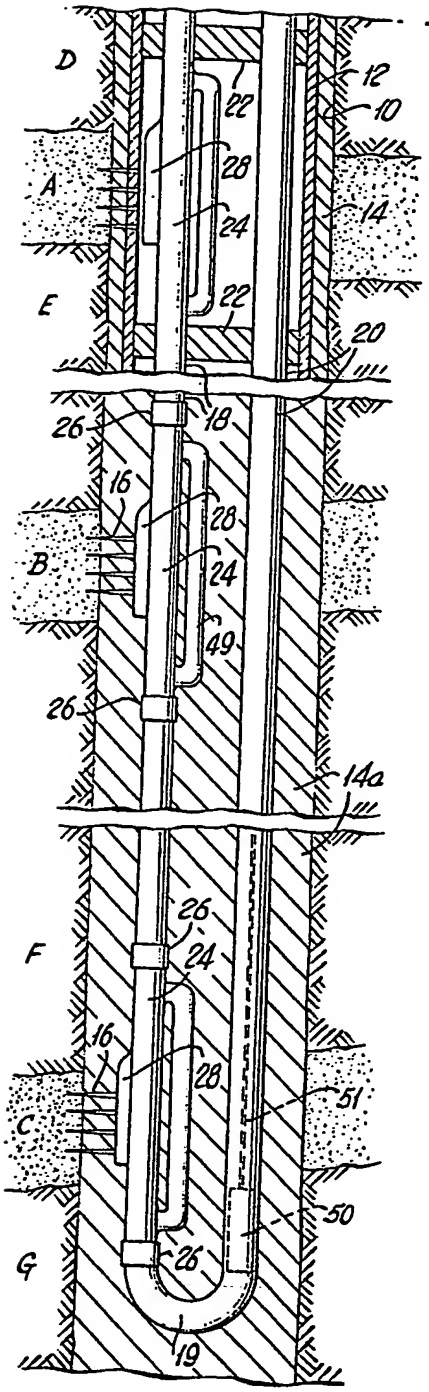

Fig.2.